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PROTON-PROTON SCATTERING IN CHARGED SCALAR THEORY

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February 21, 1950

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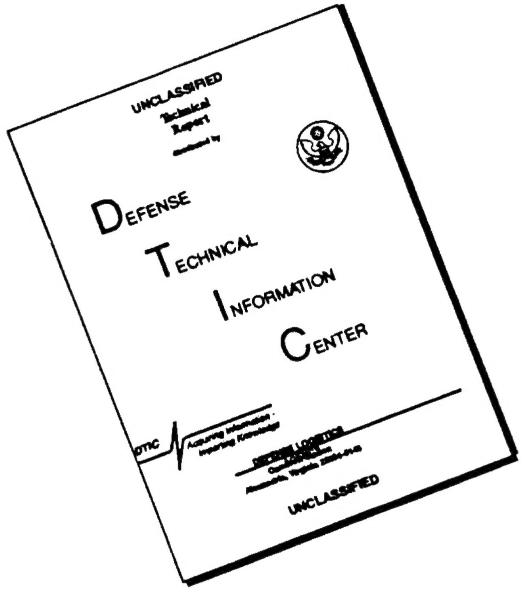

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The recent measurements by the Berkeley experimentalists[1] of 345 Mev proton-proton and 280 Mev neutron-proton scattering have shown a remarkable difference in the two types of scattering. The neutron-proton scattering has a cross section of 36 millibarns and is very strongly peaked at 0 and 180 degrees in the center-of-mass system; the proton-proton scattering has a much larger differential cross section at 90 degrees and is nearly isotropic in the angular range 20-160 degrees.

An immediate qualitative explanation of these differences is to assume that neutron-proton scattering takes place in lowest order through the exchange of single charged mesons, while proton-proton scattering in lowest order occurs only through the exchange of pairs of charged mesons. This is equivalent to assuming that protons are coupled directly only to positive mesons.[2] If the calculations of Watson and Lepore,[3] on the radiative corrections to nuclear forces for pseudo-scalar theory, are considered in this hypothesis, it is found that not even rough qualitative agreement can be obtained with the experimental results. We therefore have calculated the neutron-proton and proton-proton scattering to 4th order in the meson nucleon coupling using charged scalar theory.

It is found that the only important contributions to the 4th order processes come from the exchange of 2 mesons. Terms corresponding to the polarization of the vacuum by the mesons give negligible contributions. The resulting 4th order contribution to the S-matrix, ignoring corrections of order v^2/c^2, which are less

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[1] R. Christian, Bull. Am. Phys. Soc. 24, No. 8 (1949)

[2] Experimental observations at Berkeley on meson production have not yet indicated conclusively that neutral mesons are coupled directly to protons.

[3] Physical Review 76, 1157 (1949)

than 10 percent, is

$$(1) \qquad M_4(PP) = i\left(\frac{f^2}{2\pi}\,\frac{1}{2\pi}\right)^2 \left(V^4_{PP} - \text{exchange term}\right)$$

where

$$(2) \qquad V^4_{PP} = \frac{1}{M^2}\int_0^1 dx \int_0^x dy \; \frac{4y}{\left[y^2 + (1-y)\rho + (1-x)(x-y)\theta\right]^2}$$

and

$$\rho = \mu^2/M^2$$

$$\theta = (\vec{P}-\vec{P}')^2/M^2c^2$$

The contribution to N-P scattering in 4th order is very similar to that given by (1). It is apparent that since these matrix elements depend only on the momentum transfer, they can be expressed in a coordinate representation as purely static potentials. It is interesting to observe that the P-P scattering given by (1) is almost exactly equivalent to that given by the Born approximation applied to the static Yukawa potential[4]

$$-\left(\frac{f^2}{2\pi}\,\frac{1}{2\pi}\right)^2 \frac{11.15}{4\pi}\,\frac{e^{-kr}}{r}$$

where

$$k = 2.80\,\mu c/\hbar = .207 \times 10^{-14}\,\text{cm}^{-1}$$

The differential cross section at 180 Mev for the N-P scattering including the 2nd order contribution, and for the P-P scattering are given in Figure 1. Corrections of order v^2/c^2 have been included. It is apparent that the inclusion of the 4th order N-P scattering tends to reduce the asymmetry of the N-P scattering about 90 degrees, and that the P-P scattering is much less strongly peaked at 180 degrees than the N-P scattering. These are in the direction of the effects shown by the experimental measurements. It is also apparent, however, that for $\frac{f^2}{2\pi} \sim \frac{1}{2}$,

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[4]The range of this potential is too short to agree with measurements of low energy P-P scattering.

the contributions of the 4th order terms are much too small. The P-P total cross section is less than 1/10 that for the N-P scattering.

The failure of the scalar theory to give a better qualitative explanation of the experimental observations is due to the smallness of the 4th order contributions. It actually appears that the weak coupling approximation can be applied to scalar theory with considerable justification. However, couplings which are strong enough to predict sufficiently large P-P scattering in 4th order would at the same time invalidate the neglect of processes of even higher order. Inclusion of such processes would tend to remove the asymmetry in the N-P and P-P scattering which exists for a charged theory only if the lowest few orders in which the process can take place are considered.

There does not appear at present to be any simple way of applying meson theory in even a very qualitative way to the processes of high energy nucleon-nucleon scattering. Both the weak and strong coupling approximations seem to be invalidated by comparison of such calculations with experiment. It is not impossible, however, that in the region of intermediate coupling some of the asymmetry in the N-P and P-P scattering might be retained, while at the same time the correct magnitude of the forces be predicted.

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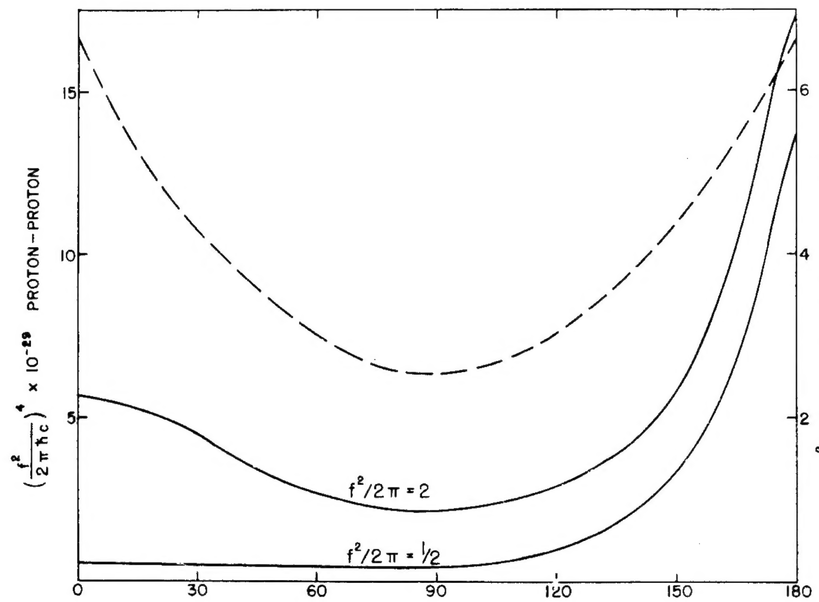


N-P SCATTERING (SOLID CURVES) AND P-P SCATTERING (DASHED CURVE) AT 180 MEV FOR THE CHARGED SCALAR MESON THEORY.

Fig. 1

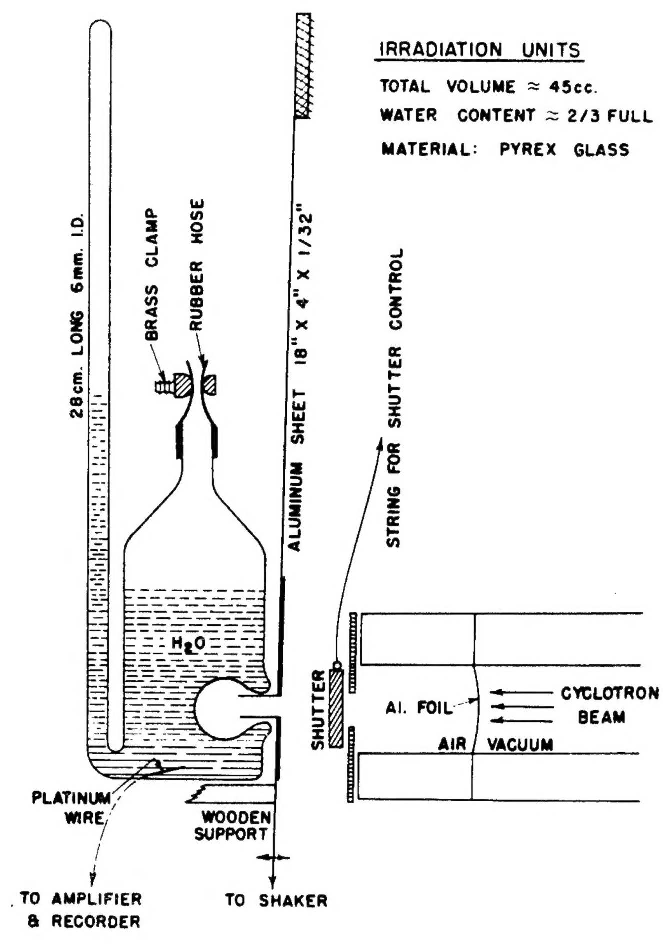


Fig. I-1

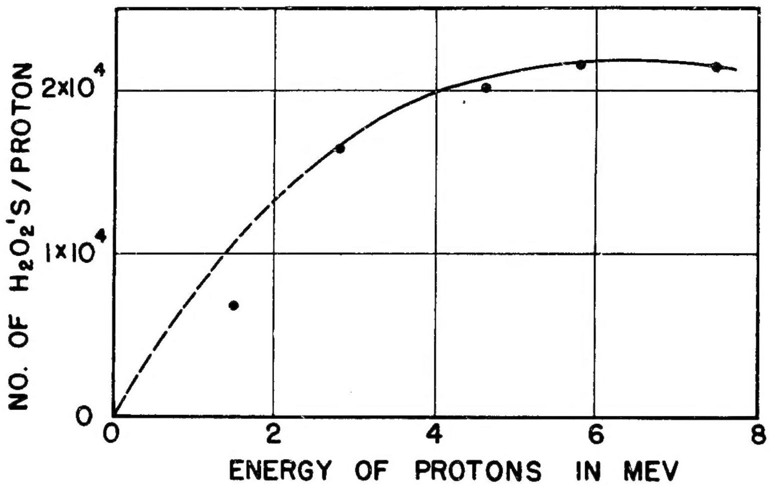


Fig. I-2

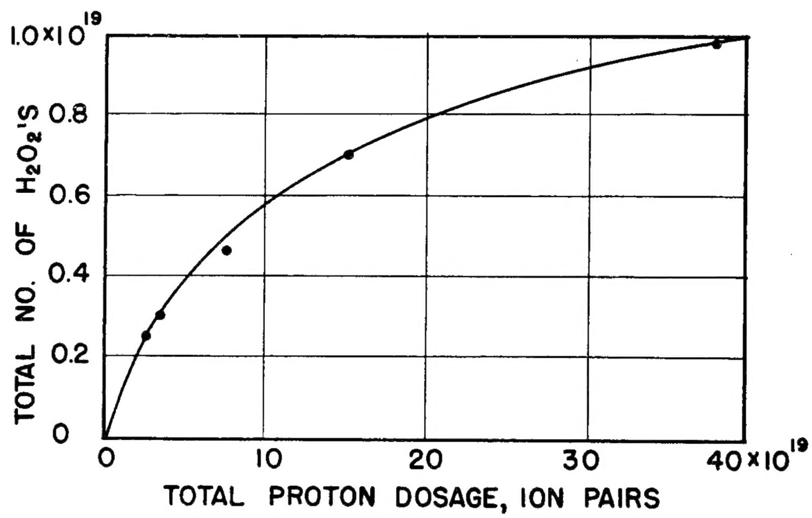


Fig. I-3

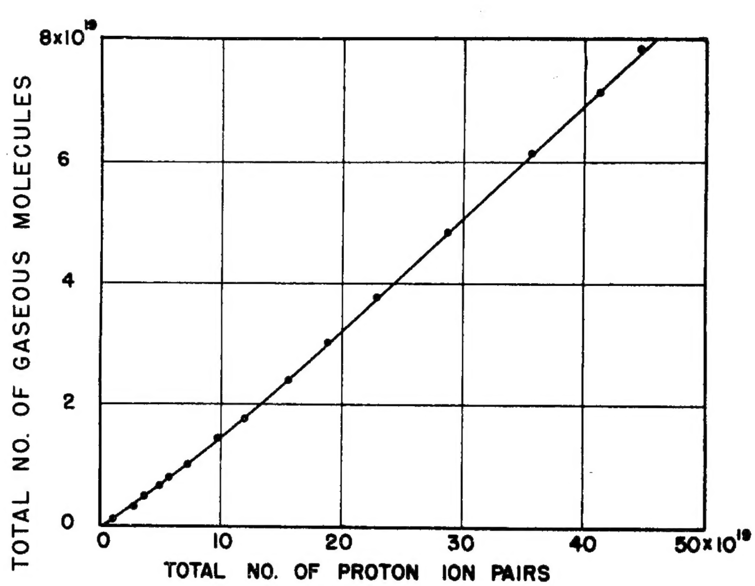


Fig. I-4

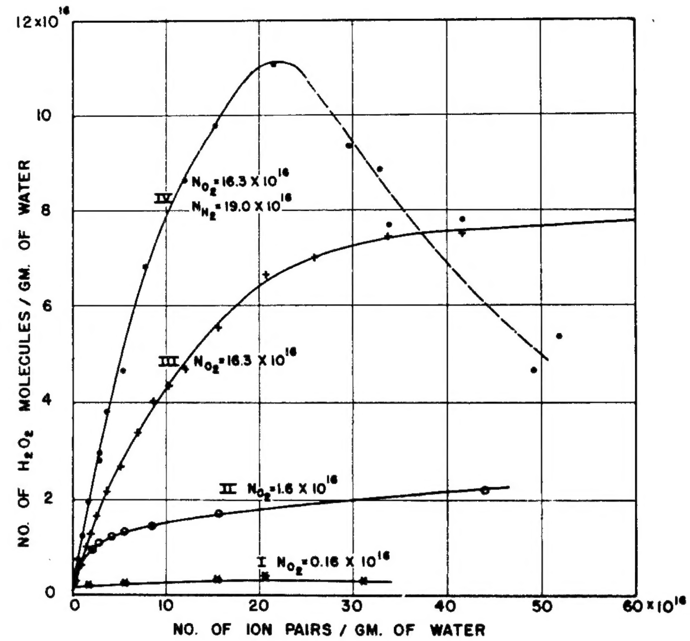


Fig. II-1

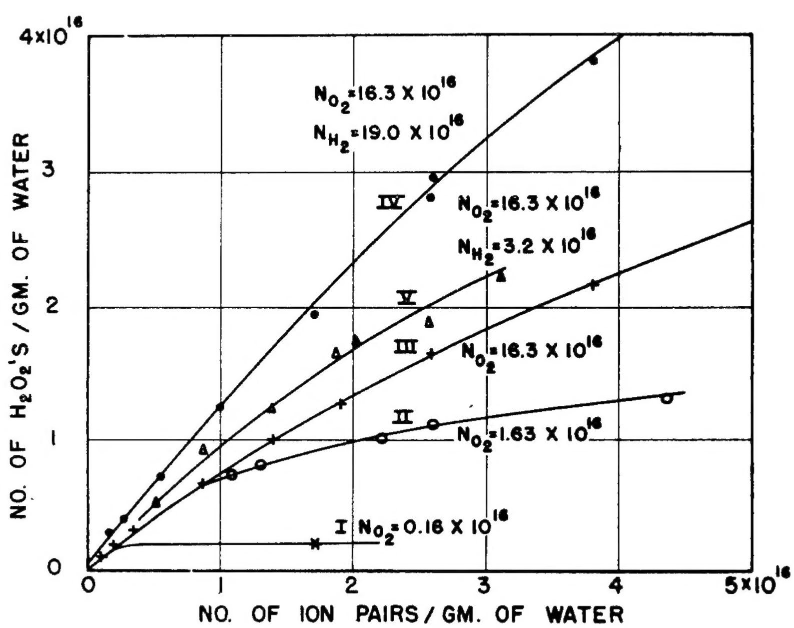
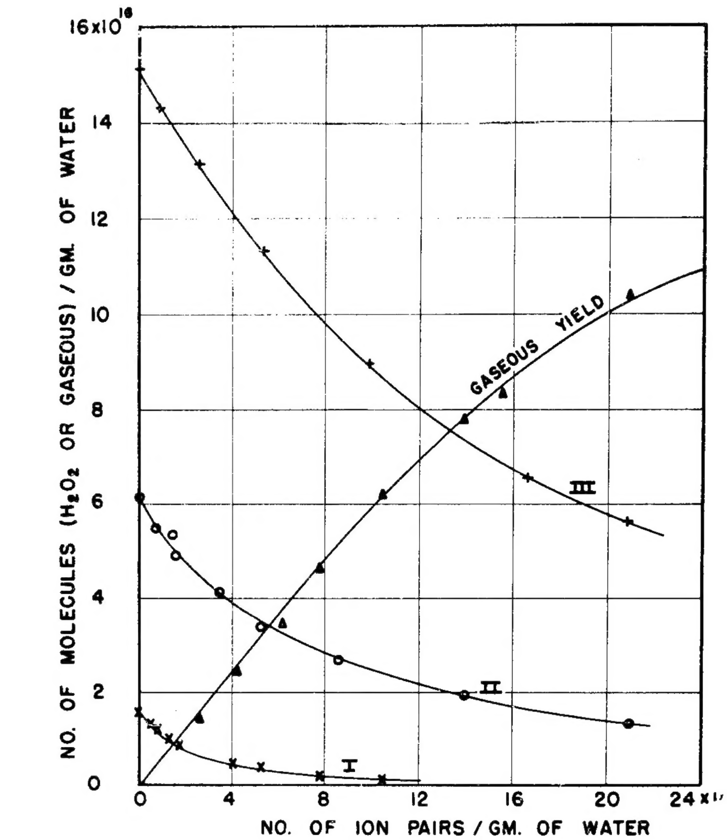


Fig. II-2



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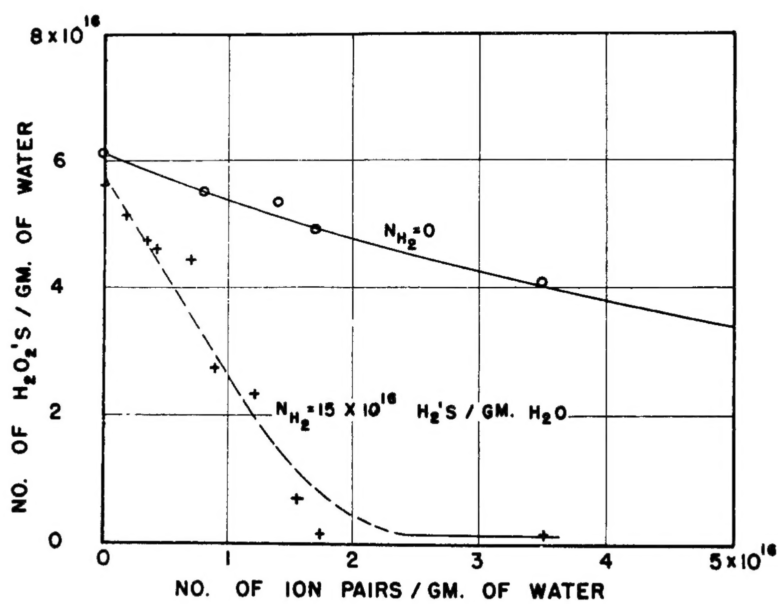

Fig. II-4

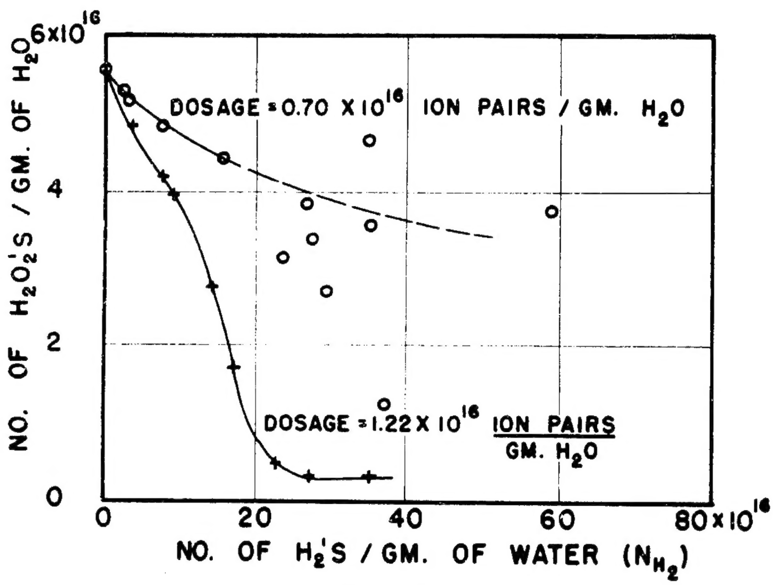

Fig. II-5

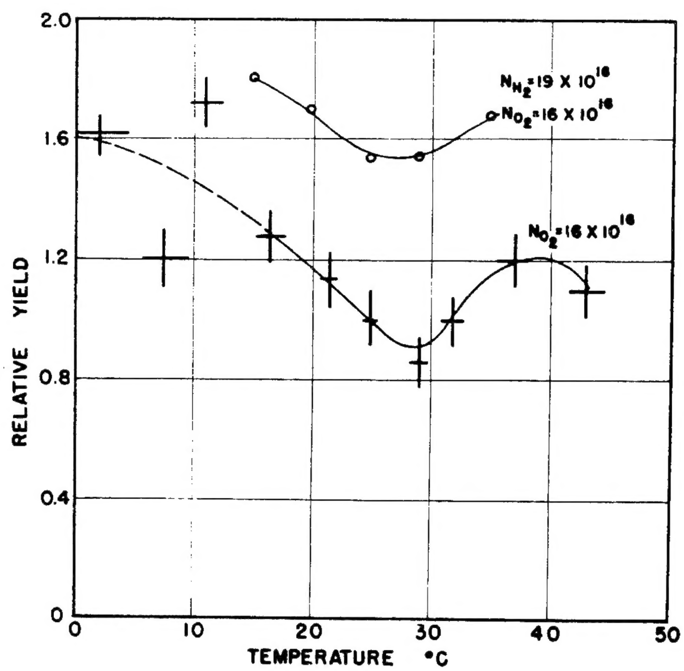

Fig. II-6

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